

Lexical–semantic priming effects during infancy

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When and how do infants develop a semantic system of words that are related to each other? We investigated word–word associations in early lexical development using an adaptation of the inter-modal preferential looking task where word pairs (as opposed to single target words) were used to direct infants' attention towards a target picture. Two words (prime and target) were presented in quick succession after which infants were presented with a picture pair (target and distracter). Prime–target word pairs were either semantically and associatively related or unrelated; the targets were either named or unnamed. Experiment 1 demonstrated a lexical–semantic priming effect for 21-month olds but not for 18-month olds: unrelated prime words interfered with linguistic target identification for 21-month olds. Follow-up experiments confirmed the interfering effects of unrelated prime words and identified the existence of repetition priming effects as young as 18 months of age. The results of these experiments indicate that infants have begun to develop semantic–associative links between lexical items as early as 21 months of age.

Keywords: language development; mental lexicon; infancy; semantic priming; associative priming

A plethora of studies investigating early lexical development have demonstrated that infants are sensitive to word–world associations at least as early as their first birthday (Reznick 1990; Meints *et al.* 1999; Tincoff & Jusczyk 1999; Schafer 2005; Pruden *et al.* 2006). These associations form the basis of infants' early vocabularies and accumulate rapidly during the second year of life. However, virtually nothing is known about infants' knowledge of word–word associations which eventually form the basis of the network of meanings underlying the adult semantic system. This study uses the inter-modal preferential looking (IPL) task to investigate whether related words facilitate online lexical processing at 18 and 21 months of age, a crucial period in early word learning. A demonstration of early semantic–associative priming effects has the potential to provide a fundamental source of information about the organization of word meaning in the developing lexicon. The rationale of the studies reported here is that related and unrelated words should differentially impact the amount of visual attention that infants direct towards a target image in a preferential looking task. By examining the pattern of priming effects observed for different pairs of words, we aim to identify the structural linkages that bind words together in the infant lexicon and to target when these structures show evidence of emerging.

Models of lexical representation assume the existence of an interconnected network. For Fodor (1983), words that frequently co-occur in language (e.g. table–chair) form part of this network. Collins & Loftus (1975) proposed a model in which words are organized in a

semantic network of interconnected nodes of similar meaning. For instance, the word 'dog' primes the word 'cat' as a consequence of an activation process that spreads across links. In contrast, distributed models of semantic memory (McRae & Boisvert 1998; Cree & McRae 2003) assume that lexical concepts are interconnected owing to their overlap in features (e.g. fur, claws, curvilinear body for cat and dog). Although these models propose different ways by which one concept affects recognition of another, both models consider that properties of concepts are the core of the semantic network.

Studies of word associations have demonstrated that prior exposure to a related word facilitates subsequent word processing in adults and school-age children: they are both faster and more accurate if a preceding word is related to a subsequent word (Neely 1991; Nation & Snowling 1999). Although semantic priming effects have been found using non-linguistic stimuli such as pictures and sounds (Bajo 1988; Ballas 1993; Orgs *et al.* 2006), in this paper, we focus on linguistic priming effects. Priming effects are typically explored via the lexical decision task (Fischler 1977; Perea & Rosa 2002), the naming task (Thompson-Schill *et al.* 1998) and occasionally using the event-related potentials technique (Holcomb & Neville 1990; Koivisto & Revonsuo 2001). We propose an adaptation of the IPL task (Golinkoff *et al.* 1987) to explore early priming effects in infancy. Previous adaptations of this task have been successful at showing effects of prior linguistic or visual information on infants' subsequent word–object processing (N. Arias-Trejo 2005, unpublished doctoral thesis; Styles & Plunkett 2009).

A common effect encountered in previous studies is the so-called *semantic priming* effect (see Neely 1991; Lucas 2000 for reviews) originally reported by

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Meyer & Schvaneveldt (1971). Adults respond faster and more accurately to a target word that has been immediately preceded by a semantically related prime word. Another effect commonly reported is the *associative priming* effect where an associative relation between words can facilitate responding to a target, even though the target is semantically unrelated to the prime (Alario *et al.* 2000; Perea & Rosa 2002; Ferrand & New 2003). While associative relations reflect word use, semantic relations reflect word meaning. However, it is unclear whether semantic or associative relations produce a stronger priming effect. Previous studies with adults have found more reliable priming effects for words that are both semantically and associatively related (e.g. dog–cat) than for words that are only semantically (e.g. dog–elephant) or associatively (e.g. dog–bone) related (Moss *et al.* 1995; McRae & Boisvert 1998; Perea & Rosa 2002). Perea *et al.* (1997) failed to find priming effects when category coordinates did not have an associative relation (arm–nose), but did find priming effects for related pairs that did not share categorical status (cradle–baby), as well as for associatively and categorically related pairs (doctor–nurse). In contrast, Perea & Rosa (2002) reported priming effects with synonyms, antonyms and coordinates for pairs that were semantically related but associatively unrelated. Likewise, McRae & Boisvert (1998) suggest that priming effects are not the consequence of mere lexical association, as priming effects are more reliable for non-associated but semantically related words than associatively related words. With the purpose of maximizing the probability of finding early evidence of priming at the level of word meaning, our experiments test word pairs that are both semantically and associatively related according to adult norms (Kiss *et al.* 1973; Moss & Older 1996).

A confluence of different factors, such as stimulus similarity and the timing between prime and target words, are known to modulate priming effects with adults (Holcomb & Neville 1990; Anderson & Holcomb 1995; Perea & Rosa 2002). There is a general consensus that semantic and associative priming effects can be automatic, independent of attention or awareness and can tap into lexical–internal processes (Neely 1977). Automatic priming effects are induced when the interval between the prime and target is shorter than 400 ms (Posner & Snyder 1975). Effects are supposed to last for less than 1000 ms (Neely 1977), although it has been argued that this duration can be extended to 2000 ms (Deacon *et al.* 1999). On the assumption that infant lexical priming is less robust and less efficient compared with adult priming, we employed a short prime–target inter-stimulus interval (ISI) and a short stimulus-onset asynchrony (SOA) of 200 ms each to maximize the likelihood of detection of priming effects and to avoid strategic (non-automatic) responses.

A number of attempts have been made to evaluate priming effects during early childhood (Goldberg *et al.* 1974; McCauley *et al.* 1976; Schvaneveldt *et al.* 1977; Church & Fisher 1998; Krackow & Gordon 1998; Nation & Snowling 1999). Some of these demonstrate that word priming facilitates the recognition of words subsequently presented under

distorted conditions. For example, adults, 2.5- and 3-year olds more accurately identify low-pass-filtered words, previously presented unfiltered in the same session, than words that had not been primed in this manner (Church & Fisher 1998). These results indicate that auditory word priming can play a role in the development of an auditory lexicon. Goldberg *et al.* (1974) have shown that when pairs of taxonomically related objects (e.g. elephant–giraffe) or unrelated objects (e.g. dog–plate) were placed in different boxes, 29–35-month olds recalled the names of the related objects significantly more often than the names for the unrelated objects, suggesting that taxonomically related objects can prime each other's names. However, these priming effects in children are not restricted to taxonomic relations. Krackow & Gordon (1998) found in a cued recall task that 3–5-year olds were better at recalling target words for items in event-based categorical relations or slot fillers (egg–cereal) than taxonomic coordinates (cereal–rice). Krackow & Gordon's (1998) results can be partially explained by the low association strengths between the taxonomic coordinates compared with higher association strengths between event-based categorical relations, suggesting that priming effects derive from associative relations between words. Likewise, McCauley *et al.* (1976) reported that the speed of 6-year olds' target picture naming is faster when a prime picture and a target picture are thematically related as opposed to taxonomically related. In contrast, 8-year olds showed facilitation for both thematically and taxonomically related pictures. Nation & Snowling (1999) found that both taxonomic (category coordinates) and thematic relationships (function-related words) prime 10-year-old normal and poor readers' reaction times in an auditory lexical decision task; however, taxonomic priming (category coordinates) was found with poor readers only if the pairs shared high association strength. Finally, Schvaneveldt *et al.* (1977) found in a lexical decision task that 7.6- and 9.5-year olds, regardless of their reading skills, were faster and more accurate to read pairs of associated written words than non-associated words, showing that semantic context influences early written word recognition. These studies indicate that children's lexical memories encode both thematic and taxonomic relationships between pairs of objects, pictures or words. Thematic relations seem to provide more robust priming effects than taxonomic relations and are apparently mastered earlier. However, little is known about the manner in which infants encode relations among words.

Some recent research using event-related potentials (ERPs) has explored whether patterns of priming can be detected during infancy (Friedrich & Friederici 2004, 2005; Torkildsen *et al.* 2007). The ERP results reported in Friedrich & Friederici's studies (2004, 2005) suggest the presence of priming-like effects in infants as early as 14 months of age: infant ERPs revealed an early negativity for congruous associations (the word dog together with a picture of a dog), and a later N400-like negativity for incongruous associations (the word dog together with a picture of a cat). Torkildsen *et al.* (2007) explored whether the N400 is

sensitive to categorical relatedness at 24 months of age by presenting auditory pairs of words drawn from the same superordinate category (e.g. dog–horse) or from different categories (e.g. car–apple). Earlier N400-like responses (200–400 ms) were found for related pairs and later N400-like responses (600–800 ms) to unrelated pairs, suggesting that labels taken from the same superordinate category had closer relations than labels from different superordinate categories.

Though suggestive, these pioneering explorations do not allow us to derive conclusions about the semantic–associative relationship between the words themselves in the infant lexicon. In the first case (Friedrich & Friederici 2004, 2005), different responses to congruent and incongruent associations show that infants are sensitive to the relationship between a word and a visual referent but do not specify how word–word associations may be organized in an extended network. Furthermore, although Friedrich & Friederici (2004) identified differences between infants' responses as an effect of vocabulary size, they did not consider infants' knowledge of the words used in the experiment; therefore, it is difficult to know whether infants were aware that the two stimuli (the word and the picture) did not match or whether they were responding on the basis of a single unknown, either the word or the picture. In the second case (Torkildsen *et al.* 2007), different event-related potentials to categorical matches versus mismatches show infants' sensitivity to the relationship between two words. However, the ERP responses may be driven by a variety of factors, including the similarity of the concepts underlying the words, the semantic relationships between the words themselves or the strength of the associations between the words. Furthermore, Torkildsen *et al.* (2007) did not provide an independent evaluation of the lexical status of the words used in their experiment. Therefore, one cannot rule out the possibility that the different ERP signatures for same versus different categories are driven by the relationship between known words or unknown words. Even if the different ERP signatures derive from word-level relationships, it is unclear whether these findings are driven by associative strength or categorical relationships. The analysis presented by Torkildsen *et al.* (2007) does not allow us to evaluate these important distinctions between the selected pairs.

Other recent research by Fernald (2005), using a looking-while-listening procedure, suggests that young children can use verbs to anticipate the referent of a subsequent target label. Twenty-seven-month olds looked more quickly to a matching picture when target words were presented in semantically related sentence frames (e.g. drive the car) than when presented in neutral frames (e.g. see the car). These results parallel the pattern of responses obtained by Altmann & Kamide (1999) with adults: visual inspection of a scene containing various target and distracter objects is driven by the predictive relationships between verbs and their corresponding potential noun arguments (e.g. eat the cake), suggesting that sentence processing is highly influenced by the relationship between words.

A recent attempt to test early word associations by Styles & Plunkett (2009) found that 24-month olds but not 18-month olds looked more at target images,

in an IPL task, when presented with taxonomically and associatively related word pairs than with unrelated word pairs. This result indicated that priming effects can be observed during infancy. However, this study failed to identify the locus of the priming effect. The absence of an appropriate control condition meant that word–picture priming as well as word–word priming could equally well explain the pattern of results obtained with the 24-month olds. Thus, it was possible that infants' preference for the target picture was driven by an overextension strategy: for example the prime word (e.g. dog) being applied to a target picture (e.g. cat), rather than by a lexical relationship between the two words.

In the current study, we developed a new experimental design that permits an evaluation of whether infants respond to word relatedness (e.g. between the words cat and dog) rather than to a relation between the prime word and the target picture. This was achieved by comparing infants' performance on trials that presented prime–target word pairs to trials in which the prime but not the target was named. If the priming effect is mediated through the lexical relations between the pairs of words rather than by a direct effect of the prime on the infants' preference for the target object, then priming should only occur if the target is named. In contrast, if the prime label has a direct effect on infants' preference for the target object, then word–picture priming should occur in the absence of the target label. Importantly, in order to establish whether the prime facilitated lexical recognition of the target word, we also compared infants' responses to related and unrelated word pairs.

In summary, we tested four types of prime–target relationships: (i) related prime–target named, (ii) related prime–target unnamed, (iii) unrelated prime–target named and (iv) unrelated prime–target unnamed. For simplicity, we will abbreviate these conditions as: (i) Prime–Target, (ii) Prime–Look, (iii) Neutral–Target and (iv) Neutral–Look. We decided to focus on 18- and 21-month-old infants. It is well known that infants make substantial gains in their vocabulary during this period (Fenson *et al.* 1994). Given that the emergence of lexical structure may be closely related to the size of infant vocabulary, the choice of 18- and 21-month olds enables a closer investigation of the quantitative prerequisites for the development of this lexical structure.

1. EXPERIMENT 1

Experiment 1 compares 18- and 21-month olds' visual preferences for a target over a distracter object when they have just heard a pair of related or unrelated words. In order to evaluate the impact of the prime word itself, priming is also tested when the target object is not labelled to test whether infants establish a visual match. We also include a neutral baseline condition in which there is neither a related prime nor a named target.

(a) Method

(i) Participants

Fifty-five 18-month olds (27 males and 28 females) and 56 21-month olds (26 males and 30 females)

Table 1. Target and distracter pairings used for the 24 primes in Experiment 1 in the Prime–Target condition. The verb used in the introductory carrier phrase for each prime word is indicated immediately after the prime.

PRIME	target	distracter	PRIME	target	distracter
SWING/saw	slide	sock	SHOE/bought	sock	slide
PARK/saw	tree	trousers	BUTTON/bought	trousers	tree
SHEEP/saw	cow	car	BIKE/saw	car	cow
COT/bought	bed	bowl	SPOON/bought	bowl	bed
APPLE/ate	banana	bird	DUCK/saw	bird	banana
ELEPHANT/saw	mouse	moon	SUN/saw	moon	mouse
NAPPY/got	bib	ball	BALLOON/bought	ball	bib
PIG/saw	horse	hand	FOOT/saw	hand	horse
CAT/saw	dog	door	WINDOW/saw	door	dog
LION/saw	tiger	train	BUS/saw	train	tiger
HAT/bought	coat	cup	PLATE/bought	cup	coat
BISCUIT/ate	cheese	chair	TABLE/saw	chair	cheese

comprised the final sample. The data from 12 18-month olds were not analysed owing to their lack of familiarity with 50 per cent or more of the presented words as reported by their parents ($n = 8$) or their failure to pay attention to more than 50 per cent of the trials ($n = 4$). These infants were eliminated because they provided an insufficient number of trials to obtain aggregated means for each condition. The mean ages were: 18:00 months (range 17:17–18:25) and 20:30 months (range 20:13–21:21). All infants had no known hearing or visual problems and were recruited from local maternity wards and playgroups. Infants came from homes where British English was the primary language.

(ii) Stimuli

We selected 48 concrete nouns that were familiar to 18-month olds with frequencies above 60 per cent as indicated by previous studies (Dale & Fenson 1993; Fenson *et al.* 1993; Hamilton *et al.* 2000). From these words, 24 served exclusively as primes and 24 exclusively as targets or distracters. The images of the 24 target words were organized into 12 yoked target–distracter pairs. Targets were paired with distracters such that their labels shared the same phonological onset and were selected so that there was neither attested associative strength nor a semantic relationship between them. A prime word was associatively and semantically related to the label of one member of a target–distracter pair while another prime word was associatively and semantically related to the other member of the pair. The prime–target pairs were selected to have high associative strength according to published adult associative norms (Kiss *et al.* 1973; Moss & Older 1996). The target and prime words were also highly imageable (Bird *et al.* 2001; Cortese & Fugett 2004). Table 1 lists all possible target–distracter pairings used in Experiment 1.

At present, it is unknown whether adult word associations parallel those of infants. Although some studies have reported children's word association norms (Koff 1965; Entwisle 1966; Palermo & Jenkins 1999), they are not suitable for use with infants for the following reasons: (i) the majority of the sample words are not part of infants' vocabularies (e.g. cabbage), (ii) the sample words are not necessarily readily

imageable (e.g. light) and (iii) they include word categories other than nouns (e.g. verbs and adjectives) which are not the target of study of this work. The British norms employed for the purpose of this research (Kiss *et al.* 1973; Moss & Older 1996) included a sufficient number of nouns that could be presented to infants under the age of 2. Furthermore, the input to British infants may well reflect the associative norms found for British adults and contribute to the underlying associations that infants form themselves.

Auditory stimuli were digitally recorded in the same session by a female voice at 22.05 kHz into signed, 16-bit files in child-directed speech. They were edited to remove background noise, head and tail clicks and to match for peak-to-peak amplitude. The 24 target words were recorded in isolation. The prime words were embedded in one of the following carrier phrases: 'I saw a/I bought a/I got a/I ate some' (table 1). The prime word was always placed at the end of the sentence. The word 'Look' was also recorded for use in the Prime–Look and Neutral–Look conditions.

Visual stimuli: 24 images of the selected target–distracter pairs were employed. Images were colourful computerized photos of typical exemplars of real objects. These images had been rated by adults in a previous study as typical members of their basic-level categories. All images were the same size (320 × 320 pixels) and had five per cent grey background to reduce brightness on the screen.

(iii) Procedure

Infants were tested using an adaptation of the IPL procedure. The infant sat centrally on his/her caregiver's lap in front of a large plasma screen that displayed the visual stimuli. The target–distracter images were shown at the infant's eye level, at a distance of approximately 70 cm. Each image measured 32 × 32 cm and they were displayed 30 cm apart. Two loudspeakers presenting the auditory message were mounted centrally above the screen. Two hidden miniature video cameras mounted side by side above the screen and aligned to the horizontal midpoint of each picture permitted digital recording of a split screen twin image of the infant's visual fixation on each image. Parents were

Table 2. Example sequence of 12 trials in Experiment 1.

trial	prime word	target picture	distracter picture	condition	prime and target words
1	SWING	slide	sock	Prime-Target	swing-slide
2	BIKE	tree	trousers	Neutral-Look	bike-look
3	SHEEP	cow	car	Prime-Target	sheep-cow
4	DUCK	bowl	bed	Neutral-Target	duck-bowl
5	APPLE	banana	bird	Prime-Look	apple-look
6	TABLE	mouse	moon	Neutral-Look	table-look
7	WINDOW	ball	bib	Neutral-Target	window-ball
8	FOOT	hand	horse	Prime-Target	foot-hand
9	CAT	dog	door	Prime-Look	cat-look
10	SHOE	train	tiger	Neutral-Look	shoe-look
11	PIG	coat	cup	Neutral-Target	pig-coat
12	BISCUIT	cheese	chair	Prime-Look	biscuit-look

instructed to remain quiet, close their eyes and wear headphones through which they heard music, in order to avoid influencing the infant's eye fixations during the presentation of the stimuli. The experimenter remained out of the infant's sight during the task and managed the experimental computer. The test lasted for about two minutes.

(iv) *Experimental design*

The test consisted of 12 trials, three per condition: (i) Prime-Target (e.g. cat-dog), (ii) Prime-Look (e.g. cat-look), (iii) Neutral-Target (e.g. plate-dog) and (iv) Neutral-Look (e.g. plate-look). In the Prime conditions, the prime word is semantically and associatively related to the label for the target image. In the Neutral conditions, the prime is unrelated to both stimulus images. In the Target conditions, the target image is named. In the Look conditions, the target image is unnamed. As mentioned previously, prime and target labels have no attested semantic or associative relation to the distracter label.

Phonological onsets of the labels for the target and the distracter words were identical. This control prevented infants from disambiguating the two pictures on the basis of the initial sound of named targets (Swingley *et al.* 1998; Mani & Plunkett 2007). The prime labels had a different phonological onset to the target and distracter label in all cases, save three (swing-slide-sock, shoe-sock-slide and balloon-ball-bib) owing to the small number of appropriate words familiar to infants. Across infants, instances where the prime (related or unrelated) had the same onset as the target-distracter items were equated across the four conditions such that only one trial per infant had this combination. An example sequence of 12 trials is shown in table 2.

Each trial consisted of the following sequence: first, the carrier phrase, which ended with the prime word, was played. Two hundred to five hundred milliseconds after the beginning of the carrier phrase, an attention getter (a static circle with smooth, pale and uniform contours of red, blue and yellow) appeared at the centre of the screen for one thousand milliseconds and always disappeared two hundred milliseconds before the onset of the prime word. Two hundred milliseconds after the offset of the prime word, the target word was played. Two hundred milliseconds

after the onset of the target word, the two pictures (target and distracter) appeared simultaneously and remained visible for 2500 ms. The next trial sequence started as soon as the infant fixated the screen, after completion of the previous trial, as monitored by the experimenter. Each infant saw the 12 pairs of target-distracter pictures just once. Four different orders of presentation of the 12 image pairings were created. No infant saw more than two consecutive trials from the same condition. The side of presentation of a particular picture (left-right) and the corresponding target and distracter side were counter-balanced across infants. Both pictures in a pair served the same number of times as target and distracter across participants. Targets appeared an equal number of times on the left and right within infants. Figure 1 displays an example of a trial sequence, along with the four priming conditions.

(b) *Results*

The experimenter, blind to which particular images and auditory stimuli were being presented, assessed the digital videos off-line frame by frame (every 40 ms) to determine the direction and duration of each fixation (left, right or other). A second skilled coder evaluated the data from 10 per cent of the participants. Agreement between scorers, assessed by computing Pearson's correlation coefficients, was $r = 0.98$, $p < 0.001$. Intra-scorer mean reliability was $r = 0.99$, $p < 0.001$. The same reliability scores were obtained for Experiments 2 and 3. The proportion of total looking (PTL) and longest looks (LLK) was calculated for the 2500 ms of picture presentation. PTL is the proportion of target looking out of the total looking time to the target (T) and to the distracter (D): $(T/T + D)$. LLK compares looking at the target relative to the distracter by calculating the difference ($t - d$) between the single LLK to the target (t) and to the distracter (d). Since similar results were obtained with both measures, the results for the PTL measure are presented alone.

For each infant, individual trials that contained unfamiliar words, as reported by parents using a British adaptation of the MacArthur Communicative Development Inventory (CDI) (Hamilton *et al.* 2000), were excluded from the analysis. Words were

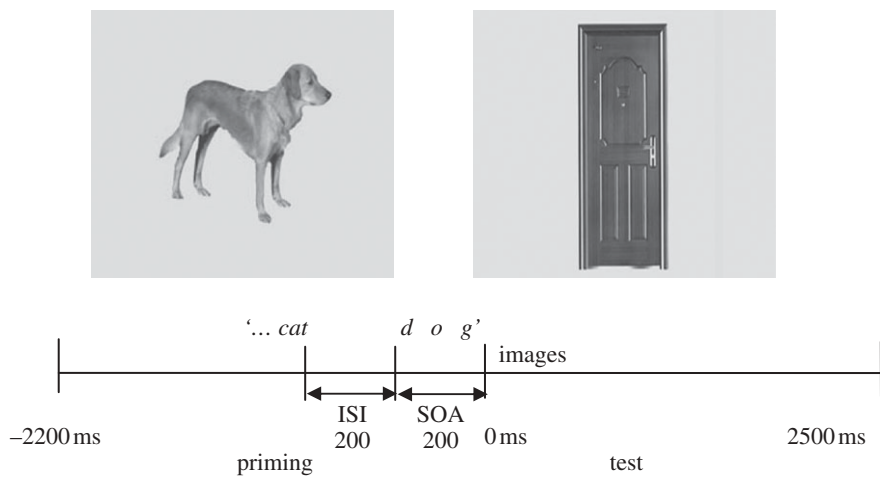


Figure 1. Example of a trial sequence and the four conditions introduced in Experiment 1. Prime–Target, I saw a cat... dog; Prime–Look, I saw a cat... look; Neutral–Target, I saw a swing... dog; Neutral–Target, I saw a swing... look.

judged to be unfamiliar if they were not in the infant's receptive vocabulary. This assessment aimed to ensure that each infant was evaluated only on her/his understanding of familiar words. Note that a word that is unfamiliar to an infant changes the status of the trial type in an uncertain fashion. By including only trials containing words that are reported as known to the infant, we can be more confident that they are responding on the basis of their word knowledge. Lexical information provided by parental reports using the CDI form was available for all the participants whose data were considered in the statistical analysis. It is worth noting, however, that the overall pattern of results did not change when trials containing potentially unknown words for the infants in both age groups were included in the analysis.

After exclusion of missing trials (when the infant looked away during the presentation of a given trial) or trials presenting an unknown word, there were 643 trials (96%) from the 672 original trials presented to the 21-month olds included in the statistical analysis distributed per condition as: 162 trials in Prime–Target, 162 in Prime–Look, 160 in Neutral–Target and 159 in Neutral–Look. For the 18-month olds, there were 486 trials (74%) from the 660 originally presented distributed per condition as: 122 trials in Prime–Target, 122 in Prime–Look, 116 in Neutral–Target and 126 in Neutral–Look. Each infant's looking times were aggregated by condition, creating a participant mean for each of the four conditions.

Figure 2 displays the PTL measure for both ages according to the priming condition: whether the prime was related (Prime) or unrelated (Neutral) to the target and whether the target was named (Target) or unnamed (Look). The looking patterns suggest that 18-month old infants showed a target preference when the target object was named, irrespective of whether the target was primed by a related or unrelated word, but failed to show any systematic preference if the target was unnamed. In contrast, the 21-month olds exhibited a preference for the target in the named-related condition (Prime–Target) only. These data were analysed in a $2 \times 2 \times 2$ analysis of variance (ANOVA) with the factors

Relationship (Prime versus Neutral), Labelling (Target versus Look) and Age (18-month olds versus 21-month olds) as a between-subjects factor. The analysis revealed a main effect of Labelling ($F_{1,90} = 19.26$, $p = 0.0001$, $\eta^2 = 0.176$) and two significant interactions: age \times labelling ($F_{1,90} = 4.99$, $p = 0.03$, $\eta^2 = 0.053$) and relationship \times age \times labelling ($F_{1,90} = 7.85$, $p = 0.006$, $\eta^2 = 0.080$).

The three-way interaction relationship \times age \times labelling showed that 18- and 21-month olds differed in their target preferences, and these differences depended on the priming condition. We report here only the relevant contrasts that allow us to test our hypotheses. To evaluate the overall priming effect, we contrasted infants' target preferences in the Prime–Target (18-month olds: $M = 0.60$, s.d. = 0.19 and 21-month olds: $M = 0.57$, s.d. = 0.15) versus the Neutral–Target condition (18-month olds: $M = 0.60$, s.d. = 0.13 and 21-month olds: $M = 0.51$, s.d. = 0.10). Target preferences in the Prime–Target condition differed from target preferences in the Neutral–Target condition for the 21-month olds ($t(54) = 3.06$, $p = 0.003$, $d = 0.45$) but not for the 18-month olds ($t(44) = 0.12$, $p = 0.90$). To test whether the prime word was sufficient to support preference for the target image, we contrasted the Prime–Target condition with the Prime–Look condition (18-month olds: $M = 0.49$, s.d. = 0.17; 21-month olds: $M = 0.49$, s.d. = 0.14). At both ages, the preference for the target image differed significantly between the two conditions: ($t(47) = 2.76$, $p = 0.008$, $d = 0.60$) and ($t(54) = 2.88$, $p = 0.006$, $d = 0.50$) for the 18- and 21-month olds, respectively.

Comparisons to chance indicated that 18-month olds looked significantly above chance in the Prime–Target condition ($t(49) = 3.80$, $p = 0.0001$) and in the Neutral–Target condition ($t(46) = 5.28$, $p = 0.0001$) but not in the Prime–Look ($t(52) = 0.37$, $p = 0.71$) and the Neutral–Look condition ($t(44) = 1.10$, $p = 0.28$). The comparisons for the 21-month olds indicated target looking above chance level exclusively in the Prime–Target condition ($t(54) = 3.52$, $p = 0.001$). Other conditions: Prime–Look ($t(53) = 0.31$, $p = 0.75$), Neutral–Target

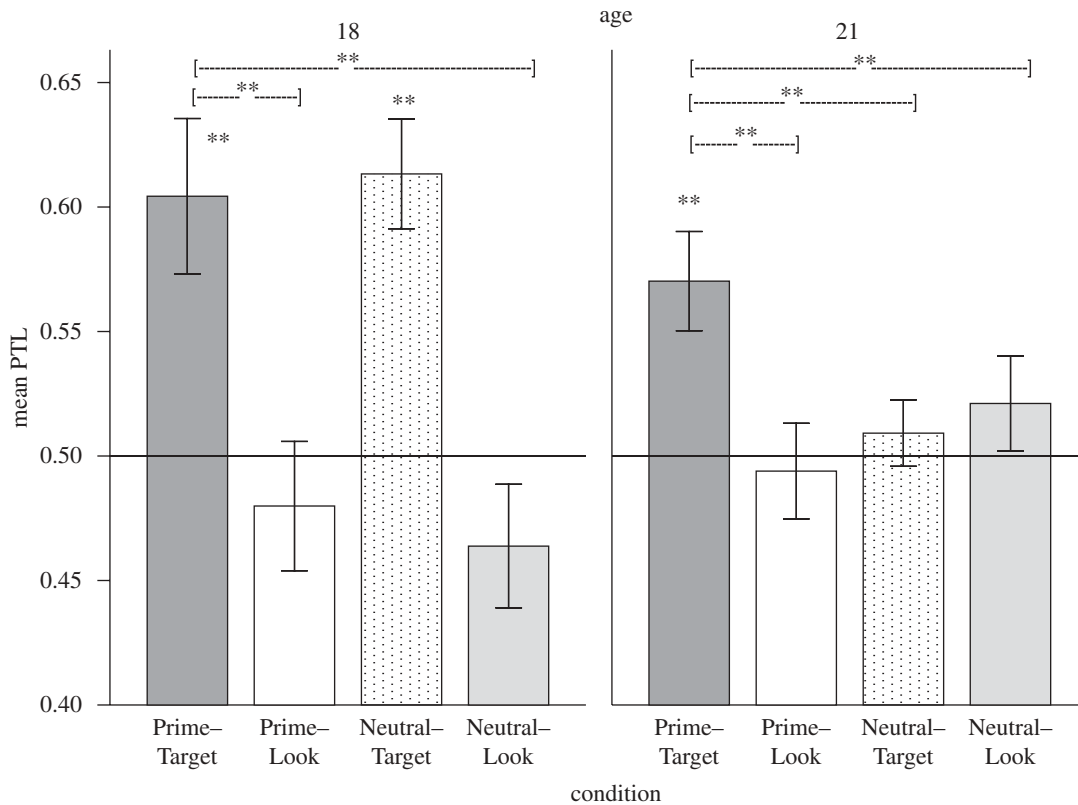


Figure 2. Mean (\pm 1s.e.) PTL measure ($T/T+D$) in Experiment 1 by Age and Condition. Central line indicates looking at chance level. Dotted lines indicate significant differences between conditions (** $p < 0.01$). Target looking above chance (** $p < 0.01$).

Table 3. Mean, range and standard deviation for the vocabulary scores in each experiment by age.

		vocabulary data											
		Experiment 1		Experiment 2		Experiment 3							
age		receptive mean (s.d.)	productive range	receptive mean (s.d.)	productive range	receptive mean (s.d.)	productive range						
18 m		212 (89)	21–404	51 (46)	0–227	225 (53)	105–334	70 (53)	4–190	182 (59)	94–381	35 (50)	0–277
21 m		296 (71)	93–429	168 (97)	6–376	274 (78)	93–396	135 (94)	23–365	276 (81)	85–427	116 (89)	0–319

($t(53) = 0.69, p = 0.49$) and Neutral-Look ($t(54) = 1.10, p = 0.27$). Finally, an independent-sample t -test indicated that 18- and 21-month olds did not differ in their target preferences in the Prime-Target condition ($t(1, 104) = 1.0, p = 0.32$).

In summary, the target preferences of the 18- and 21-month olds differed, depending both on whether the prime and the target were related or unrelated to each other and whether the target was named or unnamed. Younger infants correctly responded to the target names, regardless of the priming condition. In contrast, older infants showed systematic target preference only in the Prime-Target condition.

CDI scores for the infants are listed in table 3. To explore whether the size of the priming effect (Prime-Target – Neutral-Target) was related to infants' vocabulary size, we performed Pearson correlation tests with infants' productive and receptive vocabularies. Productive vocabulary did not correlate with the priming effect for the 18-month

olds ($r(44) = 0.001, p = 0.99$) or the 21-month olds ($r(54) = 0.19, p = 0.16$). Receptive vocabulary also failed to correlate with the priming effect for the 18-month olds ($r(44) = 0.11, p = 0.49$) or the 21-month olds ($r(54) = 0.11, p = 0.41$).

(c) Discussion

The primary aim of Experiment 1 was to test whether words possess semantic-associative relationships in infants' lexicons at 18 and 21 months of age. We examined this possibility by testing infant preferences to look at a named target picture when preceded by a semantic-associative related prime word when compared with an unrelated word. In addition, we explored whether any observed priming effects were the result of word-word priming or word-picture priming by examining infants' responses in the cases where the target was unnamed but where a related prime could potentially drive target object preferences.

The results from Experiment 1 suggest developmental changes in how the semantic–associative relationship between familiar words affects early online word processing at 18 and 21 months of age. Eighteen-month olds demonstrated recognition of the target label by exhibiting preferential looking towards the target object in both the related and unrelated conditions. However, their responses offered no evidence of a priming effect, since these infants responded in a similar manner to the named targets in both the related and unrelated conditions (Prime–Target and Neutral–Target). This finding replicates that of Styles & Plunkett (2009) where 18-month olds demonstrated a similar preference for a named target picture irrespective of whether it was presented in a related or unrelated prime condition. Furthermore, the 18-month olds showed no evidence of target object preference when the target was unnamed, even when the prime was related to the target (Prime–Look). Failure to show a target preference in the Prime–Look condition indicates either that the prime word is unable to activate a mental representation associated with the target object or that the ISI between the prime offset and the visual onset (400 ms) is too long to support word–picture priming, particularly when the interval contains another auditory stimulus (Look) and the target and distracter pictures have the same phonological onsets. A lack of target preference in the Neutral–Look condition is unsurprising as the infant is not provided with disambiguating information to motivate any preference.

In contrast, the 21-month olds showed systematic target preferences only in the Prime–Target condition. The difference in target preference between the related (Prime–Target) and unrelated (Neutral–Target) prime conditions was highly significant, indicating a strong effect of the prime on the amount of target looking. Importantly, unlike the 18-month olds, the 21-month olds failed to show recognition of the target label, as indexed by a lack of preference for the target object, when it was preceded by an unrelated prime word. This result is surprising insofar as many other studies have demonstrated that a named target promotes target object preferences in an IPL task (Golinkoff *et al.* 1987; Reznick 1990; Fernald *et al.* 1998; Meints *et al.* 1999). Failure to demonstrate a target preference when the target label is immediately preceded by an unrelated prime word indicates that the unrelated prime is interfering with the processing of the target label and identification of the target referent. The fact that this interference effect occurs just when the prime–target word pairs are unrelated indicates that 21-month old infants have begun to selectively develop semantic–associative links in their lexicons.

The 21-month olds also failed to show any evidence of target object preferences when the target was unnamed (Prime–Look), even when the prime was related to the target. Target looking only occurred when the prime and target words were related. Thus, it seems reasonable to conclude that the semantic–associative relationship between the prime and target words is driving the target object preference in the

Prime–Target condition, rather than any word–picture relationship between the word prime and the target object. It might be objected that the directive Look in the Prime–Look condition interfered with processing of the prime thereby disrupting any potential preference for the target picture guided by a word–picture relationship. This possibility seems unlikely as other IPL studies (Fernald & Hurtado 2006; Plunkett 2006) that have used Look as a directive do not report interference with target recognition. Nevertheless, we will examine this possibility further in Experiment 2.

Finally, it should be noted that the verb included in the carrier phrases (see table 1) in which the prime word was embedded provided supporting context that could have favoured some representations of an expected target word. Previous studies have shown that 27-month olds and adults exhibit anticipatory eye fixations on objects that are appropriate arguments of a verb (Altmann & Kamide 1999; Fernald 2005). However, as can be seen in table 1, from the 24 possible prime–target pairings, only two of them (‘ate an apple’ or ‘ate a biscuit’) offered this possibility. An analysis excluding these trials led to exactly the same pattern of findings reported in §2*b*.

In summary, these results support the conclusion that 21-month old infants have developed semantic–associative links in their mental lexicons. Prior activation of related words allows associated target words to drive accurate target picture identification whereas prior presentation of an unrelated word interferes with subsequent target identification. Although this interference was not observed in 18-month olds, we cannot conclude that word–word links have not developed at this age. For example, it is possible that 18-month olds take longer to retrieve the prime word and perhaps ignore it once when the target word is heard. Moreover, although we assessed infants’ familiarity with the input words, it is probable that 18-month olds are less familiar with some of the words, resulting in the formation of fewer and/or weaker word associations than 21-month olds. A task in which the prime–target words are repeated in the Prime–Target condition and the Neutral–Target words are unrelated may be more suitable to test early effects of related versus unrelated words.

2. EXPERIMENT 2

Experiment 1 revealed that at 21 months of age, linguistic processing of a target word immediately after hearing a semantically and associatively related word enables accurate target identification whereas an unrelated prime word interferes with the capacity of a target word to drive target looking. In contrast, 18-month olds were uninfluenced by the prime word, as their target looking was similarly accurate when exposed to related or unrelated pairs of words. It will be recalled that the selection of related and unrelated word pairs in Experiment 1 was based on adult norms (Kiss *et al.* 1973; Moss & Older 1996). These norms can only be a first approximation to the semantic–associative relations that exist between words in infants’ lexicons. Although the absence of a semantic–associative relation in adult norms may be

a reliable indicator of its absence in infants, the converse cannot be taken for granted: adults may have established word–word associations which infants have not yet learnt. The only case where we can be entirely confident that a prime word is related to a target word in infants is when the prime and target are identical, i.e. when the prime is repeated. Experiment 2 therefore introduces a repetition priming design with the aim of evaluating the facilitating and interfering roles of prior related and unrelated words on subsequent word processing, when the related condition consists of a repetition of the same label. We also aim to test whether 18-month olds show priming effects in a simplified task. Three conditions were employed: (i) Prime–Target in which the prime and the target were the same word, (ii) Prime–Look in which the prime was the target label itself followed by the carrier phrase Look and (iii) Neutral–Target in which an unrelated prime–target relation was presented (as in the Neutral–Target condition of Experiment 1). For simplicity, we will refer to these conditions as: (i) Prime–Target, (ii) Prime–Look, and (iii) Neutral–Target. We decided not to include the fourth Neutral–Look condition since it failed, as expected, to produce any systematic preferences in Experiment 1 and merely added to the time needed to complete the experiment.

Given the results from Experiment 1, we predicted that 21-month olds would show a priming effect, i.e. enhanced target recognition in the Prime–Target condition compared with the Neutral–Target condition. We also predicted that the Neutral–Target condition should replicate the interfering effect found in the Neutral–Target condition of Experiment 1. Finally, the Prime–Look condition permitted an evaluation of the interfering effect of an intervening directive carrier phrase when the prime is the target label itself. For the 18-month olds, we predicted that they would respond to the target name, regardless of the priming condition, as they did in Experiment 1. However, Experiment 2 also allows us to explore the possibility that a simplified task would enable 18-month olds to demonstrate sensitivity to the related versus the unrelated priming conditions.

(a) Method

(i) Participants

Thirty-nine 21-month olds (20 females and 19 males) and 39 18-month olds (19 females and 20 males) were tested. The data from one 21-month old, owing to reluctance to look at the pictures for more than 50 per cent of the trials, and two 18-month olds, owing to unfamiliarity with the names of the displayed objects, were not included in the analysis. The mean ages were 21:03 (range 20:16–21:25) and 18:05 (range 17:18–18:20). None of the infants had participated in Experiment 1.

(ii) Stimuli

Eighteen concrete nouns were selected with the same criteria and from the same sources as for Experiment 1 (Dale & Fenson 1993; Fenson *et al.* 1993; Hamilton *et al.* 2000). The nouns were: aeroplane, bear, bee,

boat, book, boot, brush, cake, chicken, clock, fish, flower, frog, juice, key, monkey, lorry and television. The carrier phrases were the same as for Experiment 1, except for ‘I ate a’ that was not employed. The eighteen object labels, the carrier phrases and the word Look were recorded and edited in the same way as for Experiment 1. Likewise, the eighteen digital pictures were edited as for Experiment 1.

(iii) Procedure

The procedure was identical to that in Experiment 1. The test lasted for approximately a minute and a half.

(iv) Design

Experiment 2 presented nine trials, three per condition: Prime–Target (e.g. boot–boot), Prime–Look (e.g. boot–look) and Neutral–Target (juice–boot). Each trial had the same sequence as in Experiment 1. Thus, the ISI and SOA were 200 ms. In Experiment 2, the constraint that target and distracter had the same phonological onset was removed, thereby making it possible to identify a larger number of suitable pairs than in Experiment 1. However, the neutral prime word in the Neutral–Target condition did not share a phonological onset with either the target or the distracter. As in Experiment 1, labels for the target and the distracter in a pair were not taxonomically related and did not share an associative relationship according to published associative norms (Kiss *et al.* 1973; Moss & Older 1996). Within these restrictions, the items were paired with each other across six different counterbalanced presentations. Infants were randomly assigned to one of these presentations. The side of presentation of a particular picture (right–left) and the corresponding target and distracter sides were counterbalanced. Both pictures in a pair served the same number of times as target and distracter across participants. Each picture was seen only once, thus the names of the targets were heard only once. The order of presentation of the trials was randomized by the presentation computer at run-time.

(b) Results

Data analysis was the same as for Experiment 1. Owing to infants’ unfamiliarity with the stimuli names or missing trials there were 331 trials (97%) from the 342 originally presented to the 21-month olds. There were similar numbers of trials in each condition: Prime–Target 109, Prime–Look 110 and Neutral–Target 112 trials. The 18-month olds’ data had 268 trials (81%) from the original 342. Again, there were similar numbers of trials retained for each condition: Prime–Target 92, Prime–Look 85 and Neutral–Target 91 trials. Looking times were aggregated by condition creating a participant mean for each of the three conditions.

The PTL and LLK analyses yielded a similar pattern of results. As for Experiment 1, we report here only the PTL results. A 3×2 analysis of variance with Condition (Prime–Target, Prime–Look and Neutral–Target) and Age (18- and 21-month olds) as a between-subjects factor was performed.

The PTL analysis yielded a main effect of Condition ($F_{2,66} = 4.66$, $p = 0.01$, $\eta^2 = 0.124$). There were no other significant main effects or interactions. Figure 3 depicts the target preference in each condition. Since there was no effect of Age in the ANOVA, mean comparisons for the three conditions were performed with the data from the two age groups combined. Target preference in the Prime–Target ($M = 0.61$; $s.d. = 0.19$) and the Neutral–Target condition ($M = 0.51$; $s.d. = 0.16$) differed significantly from each other ($t(1,70) = 3.18$, $p = 0.002$, $d = 0.54$). Target preferences in the Prime–Target and the Prime–Look condition ($M = 0.54$; $s.d. = 0.19$) differed marginally ($t(1,72) = 1.90$, $p = 0.06$, $d = 0.35$). Finally, target looking in the Prime–Look and Neutral–Target conditions did not differ ($t(1,69) = 1.21$, $p = 0.23$). We also compared the target scores for each condition against chance. The results indicated target looking above chance in the Prime–Target condition ($t(74) = 5.04$, $p = 0.0001$), a near significant preference in the Prime–Look condition ($t(73) = 1.90$, $p = 0.06$) and no systematic preference in the Neutral–Target trials ($t(71) = 0.79$, $p = 0.43$). As suggested by the lack of any interaction involving Age, analysis of the age groups separately produced the same pattern of results.

CDI scores are reported in table 3. The Pearson correlation tests between the effect of priming and infants' productive or receptive vocabularies failed to show a significant relationship at 18 months ($r(35) = 0.09$, $p = 0.61$; $r(35) = 0.10$, $p = 0.57$) and at 21 months of age ($r(34) = 0.03$, $p = 0.88$; $r(34) = 0.06$, $p = 0.72$).

(c) Discussion

The results from Experiment 2 showed that target looking at both ages was influenced by the relationship between the prime and the target words. Infants' preference for the target image was greater in the Prime–Target condition than in the Neutral–Target condition. These results indicated that infants correctly identified the target referent in the repeated Prime–Target condition but were inhibited by unrelated prime–target pairs of words. The outcome in the Neutral–Target condition replicated the interfering effect previously encountered in Experiment 1: when an unrelated prime preceded the target word, 21-month olds did not demonstrate reliable target looking. Thus, processing of two consecutive words is more challenging when their meanings are distant than when their meanings are proximate in lexical space. The latter scenario facilitates target recognition, whereas the former hinders target recognition.

While Experiment 1 failed to demonstrate an interfering effect from unrelated words at 18 months of age, Experiment 2 demonstrated that 18-month olds are sensitive to the relationship between two words. In Experiment 1, 18-month olds responded to the target name, regardless of the status of the prime word. In contrast, in Experiment 2, 18-month olds did not exhibit target looking in the Neutral–Target condition. We attribute this contrast to the simplification of the task. First, in the related condition of

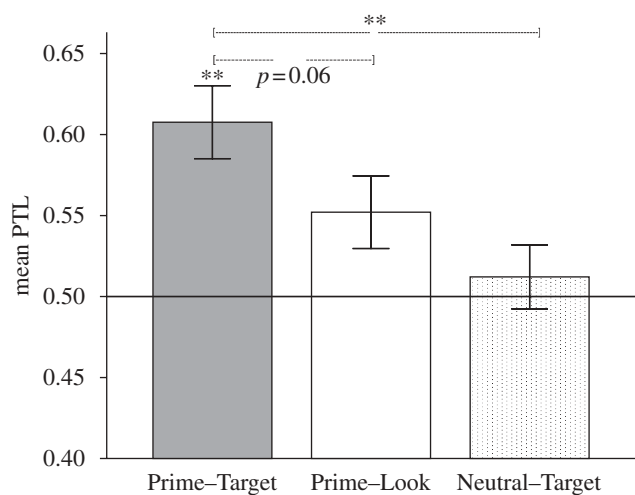


Figure 3. Mean (± 1 s.e.) PTL measure ($T/T+D$) in Experiment 2 by Condition. Central line indicates looking at chance level. Dotted lines indicate significant differences between conditions (** $p < 0.01$). Target looking above chance (** $p < 0.01$).

Experiment 2, the prime and target names were identical. Thus, the Neutral–Target condition was the only case in which two different nouns were heard, whereas in Experiment 1 half the trials contained two different nouns. As a consequence, in Experiment 1 infants heard two different nouns on 50 per cent of the trials (on Prime–Target and Neutral–Target trials) but in Experiment 2 only 33 per cent of trials (on Neutral–Target trials). Second, in Experiment 2, the target and distracter names always had different onsets. Third, the task was shorter; nine trials instead of 12 were included. We suggest that these simplifications of the task enabled 18-month olds to demonstrate a simple form of priming, namely repetition priming, thereby exhibiting an emergent appreciation of the relationship between words.

Although infants preferred to look at the target than at the distracter in both the Prime–Target and the Prime–Look conditions, the marginally significant difference between attention to the target image in these two conditions indicates that the word Look presented 200 ms after the offset of the prime word (which matched one of the available images) may have attenuated infants' target preference. However, it is clear that infants' preference for the target picture in the Prime–Look condition results from having heard the name (as a prime) of one of the pictures in the visual pair. This result is particularly noteworthy given that the infants in Experiment 1 showed no evidence for a target preference in the Prime–Look condition. This contrast indicates that the directive Look does not interfere with the impact of the prime in Experiment 1 any more than it does in Experiment 2, supporting the conclusion that the prime is only effective through its semantic–associative link with a related target word.

It could be argued that infants' target looking in the Prime–Target condition is partially induced by a phonological match between the onset of the prime and the target (being the same word), in comparison to the Neutral–Target condition in which the prime

and the target did not share onsets. In other words, it is not possible in this experiment to determine whether we have obtained a phonological priming effect rather than a semantic–associative effect. It should be noted, however, that in Experiment 1 we obtained the same priming effect with 21-month olds even though almost all the prime–target pairs shared no phonological onsets. Therefore, we would expect the semantic–associative component of repetition priming to play a causal role in Experiment 2. However, it is possible that 18-month olds did benefit from this contrast and that the observed repetition priming at this age may be primarily a phonological effect.

3. EXPERIMENT 3

The results from the previous two experiments indicate a clear priming effect in 21-month olds and some sensitivity to word pairs at 18 months of age. However, an alternative interpretation of the conditions in which infants failed to identify the target object is that target looking is attenuated simply because of memory constraints. This may be particularly relevant in the case of the 18-month olds. For example, hearing the prime named before the onset of the target–distracter picture pair may cause difficulty for the infants because they have to remember the name in the absence of any visual representation of the object. Experiment 3 evaluates this possibility by replacing the carrier phrase Look in the Prime–Look condition of Experiment 2 with silence. If memory is not a constraining factor in Experiments 1 and 2, we predict that infants will also succeed in identifying the target referent when Look is replaced by silence.

(a) Method

(i) Participants

Thirty 18-month olds (14 females and 16 males) and 30 21-month olds (14 females and 16 males) were tested. The data from two 21-month olds were not available owing to technical problems and parental interaction during test. The mean ages were 18:18 (range 17:20–18:20) and 21:03 (range 21:00–21:18). None of the infants participated in Experiment 1 or 2.

(ii) Stimuli

Eighteen concrete nouns were selected with the same criteria and from the same sources as for Experiment 1 (Dale & Fenson 1993; Fenson *et al.* 1993; Hamilton *et al.* 2000). The nouns were: aeroplane, baby, bath, bin, book, brush, butterfly, chicken, fish, flower, frog, juice, key, monkey, phone, teddy, TV and toast. Three carrier phrases were also recorded: ‘Look at this/Uh Look/Hey Wow’ and edited in the same manner as in Experiments 1 and 2. Likewise, the 18 digital pictures were edited as for Experiments 1 and 2.

(iii) Procedure

The procedure was identical to that in Experiments 1 and 2. The test lasted for approximately a minute and a half.

(iv) Design

Experiment 3 presented nine trials of target–distracter pairs. The trial began with an attention getter (blue and black small rotating circle at the top–centre of the screen) and one of the three carrier phrases which lasted on average 1200 ms. The attention getter disappeared after 1000 ms so that the carrier phrase was completed with the screen blank. While the screen remained blank, the target onset (e.g. ‘monkey’) was heard 200 ms after completion of the carrier phrase (e.g. ‘Hey wow’). The target–distracter picture onset occurred on average 375 ms after the offset of the target name. This sequence simulated the SOA of 400 ms between prime offset and picture onset, established previously. The two pictures (target and distracter) appeared simultaneously and remained visible for 2500 ms. As in Experiment 2, the target and distracter referents had different onsets. As in Experiments 1 and 2, labels for the target and the distracter in a pair did not share an associative relationship according to published associative norms (Kiss *et al.* 1973; Moss & Older 1996). Within these restrictions, the items were paired with each other across eight different counterbalanced presentations. Infants were randomly assigned to one of these presentations. The side of presentation of a particular picture (right–left) and the corresponding target and distracter side were counterbalanced. Both pictures in a pair served the same number of times as target and distracters across participants. For each infant, each picture was seen only once, thus the names of the targets were heard only once. Across infants, each target name was presented the same number of times with each carrier phrase. Infants heard each carrier phrase three times. The order of presentation of the trials was randomized by the presentation computer at run-time.

(b) Results

Data analysis was the same as for Experiments 1 and 2. In total, 244 (97%) and 206 (76%) of the trials were available from the 21- and 18-month olds’ data, respectively, after elimination of missing trials or trials presenting unfamiliar words according to CDI reports. Looking times were aggregated for the available trials of each infant, creating a participant mean.

The PTL and LLK analyses yielded the same pattern of results. As for Experiments 1 and 2, we report only the PTL results. A one-way univariate ANOVA was performed with PTL as the dependent variable and Age as a between-subjects factor. The analysis failed to identify any Age differences in infants’ target looking ($F(1,57) = 0.11$, $p = 0.74$). Mean comparisons between infants’ attention to the target versus the distracter demonstrated a reliable target preference ($M = 0.58$, $s.d. = 0.09$; $t(1,57) = 6.32$, $p = 0.0001$, $d = 1.66$). Thus, infants showed a robust ability to match a name with a target referent even when the target name was followed by silence and before the target–distracter pictures were displayed. Because in Experiment 2 infants’ performance in each condition was aggregated across three trials, a second analysis with three randomly selected

trials from Experiment 3 was performed. The same pattern of results was obtained: significant target looking ($M = 0.59$, $s.d. = 0.20$; $t(1, 55) = 3.45$, $p = 0.001$)¹ with no differences between the two age groups.

CDI scores are reported in table 3. The Pearson correlation tests between infants' proportion of target looking and their productive and receptive vocabularies failed to show a significant relationship at 18 months ($r(29) = 0.26$, $p = 0.16$; $r(29) = 0.06$, $p = 0.74$) and at 21 months of age ($r(27) = 0.03$, $p = 0.88$); $r(27) = 0.055$, $p = 0.78$).

Comparisons between infants' target looking across the three randomly selected trials in Experiment 3 and the Prime–Target, Prime–Look and Neutral–Target conditions in Experiment 2 were performed with the aim of evaluating the impact of the second word in Experiment 2. Independent-sample *t*-tests revealed that the mean target looking in the Prime–Target condition of Experiment 2 ($M = 0.61$, $s.d. = 0.19$) and the mean target looking in Experiment 3 ($M = 0.59$, $s.d. = 0.20$) did not differ significantly ($t(1,129) = 0.52$, $p = 0.60$). Likewise, mean target looking in the Prime–Look condition of Experiment 2 ($M = 0.54$, $s.d. = 0.19$) and the mean target looking in Experiment 3 did not differ significantly ($t(1,128) = 1.41$, $p = 0.16$). However, target looking in Experiment 3 and the Neutral–Target condition of Experiment 2 ($M = 0.51$, $s.d. = 0.16$) differed significantly ($t(1,126) = 2.40$, $p = 0.02$, $d = 0.42$). This last comparison indicates that infants are reliably worse on Neutral–Target trials in which two unrelated words are presented than in trials in which a named target followed by silence is introduced before the onset of the target–distracter pictures. However, the other comparisons failed to find significant differences between Experiment 3 and the Prime–Target and Prime–Look conditions of Experiment 2.

(c) Discussion

These results, together with those from Experiments 1 and 2, support several conclusions. First, robust target looking in Experiment 3 highlights 18- and 21-month olds' ability to retain a memory trace of the target label for at least 375 ms that is able to drive target recognition. Thus, memory for words does not itself seem to be a constraining factor within the timing parameters used in these experiments. Second, a direct comparison of the Prime–Look condition in Experiment 2 with Experiment 3 failed to yield a significant difference, indicating that the directive carrier phrase Look following the target word in the Prime–Look condition of Experiment 2 is at most mildly attenuating target recognition rather than disrupting it. This adds further support to the conclusion that the lack of target identification in the Prime–Look condition of Experiment 1 is owing to the absence of a related target word rather than interference from the directive Look. Comparison of the Neutral–Target trials in Experiments 1 and 2 with Experiment 3 highlights the interfering impact of the Neutral prime on target identification in the earlier experiments.

4. GENERAL DISCUSSION

Semantic–associative relatedness of words during early lexical development was evaluated by means of an adaptation of the IPL task that tests the impact of word pairs on infants' preferences for a target object. Experiment 1 used four different priming conditions to isolate the effect of semantic–associative relatedness from the effect of word–picture relatedness at 18 and 21 months of age. In Experiment 1, 18-month olds responded equally well to target names, regardless of their prior exposure to a related or an unrelated word but failed to show evidence of target recognition when the target was unnamed, even when a prime word related to the target object was heard 400 ms before the target and distracter pictures were presented. This finding underlines the importance of target naming for the 18-month olds and indicates that the initial prime word had no effect on their target preferences. Conversely, 21-month olds identified the target referent only in the Prime–Target condition in which semantically and associatively related word pairs were used. Importantly, 21-month olds failed to show target recognition in the Neutral–Target condition, thereby demonstrating the interfering effect of the unrelated prime on target recognition as compared with the effect of the prime in the Prime–Target condition. Failure to show target recognition in the Prime–Look condition also indicated that the prime word is insufficient to drive target looking when presented 400 ms before a target. This finding, together with infants' behaviour in the Prime–Look condition of Experiment 2, indicates that target looking in the Prime–Target condition is driven by a word (prime) → word (target) relation rather than a word (prime) → picture (target) relation.

The pattern of results obtained with the 21-month olds provides evidence for the claim that they have developed a mental lexicon that encodes semantic–associative relationships between some words, and that these links can facilitate the processing of lexical items. We have also seen that an unrelated prime word hinders target recognition in 21-month olds but not in 18-month olds in Experiment 1. We might attribute this apparent decrement in performance with increasing age to a reorganizational process that underpins the priming results reported. By 21 months of age, we suggest that words with related meanings form excitatory links with each other and are clustered together in lexical space, whereas words that do not share meaning are pushed further apart. The possible lack of organizational structure at 18 months old may act as a double-edged sword as far as the target label is concerned: related primes fail to facilitate target label recognition, but by the same token unrelated primes do not interfere with its recognition. The success of the 18-month olds in the Neutral–Target condition of Experiment 1, replicating a result reported by Styles & Plunkett (2009), suggests that their mental lexicon may still be organized around one-to-one associations between words and objects. However, it is also possible that 18-month olds have already begun to form semantic–associative relations between words but our experimental procedure failed to detect this, perhaps because we selected word-pairs of insufficient semantic–associative strength at

this age. Another alternative is related to memory constraints; 18-month olds may require different ISI and SOA intervals to process all of the online information in an effective manner.

Experiment 2 sought to replicate the priming effects of Experiment 1 but under conditions where we could be confident about the exact relationship between the prime word and the target word, i.e. by making them identical to each other. This experiment also aimed to reconsider priming effects at a younger age in a simplified task. If 18-month olds have begun to form semantic–associative links between words, then we would also expect them to demonstrate interference effects in the Neutral–Target condition, like the 21-month olds. In Experiment 2, 18-month olds showed the same pattern of responding as the 21-month olds, indicating sensitivity to the relationship between word pairs. Infants demonstrated systematic target looking when exposed to repeated word pairs but not to unrelated word pairs. These results provide further support for the priming effect found in Experiment 1 with 21-month-old infants and substantiate the claim that an unrelated word interferes with the processing of a subsequent target word. The simplified design of Experiment 2 also revealed that 18-month olds are sensitive to the relationship between two words, albeit under rather specific circumstances, namely that of repetition.

Experiment 3 sought to evaluate the impact that hearing a single target word followed by silence had on target recognition when the offset of the target word occurred before the onset of the target–distracter pictures. Robust target looking was found in Experiment 3, indicating that any deviations from target looking in Experiment 2 were owing to inhibitory effects arising from the lack of a relationship between the two words rather than any general memory constraints imposed by timing parameters used in these experiments. The fact that the 18-month olds showed the same pattern of findings in Experiments 2 and 3 as the 21-month olds suggests an emerging sensitivity to the relationship between word pairs even at this early age.

In all three experiments, we failed to find a significant correlation between vocabulary size and the priming effect (Experiments 1 and 2) or the naming effect (Experiment 3). Vocabulary size, *per se*, need not be a predictor of the emergence of a semantic system, though of course sufficient words need to be present in the lexicon for priming effects to emerge. The infants participating in our studies may have already acquired a sufficiently large lexicon. It is important to note that we only analysed the trials that contained familiar words for each of our participants (as primes, targets or distracters). Thus, it appears that our results did not depend on their vocabulary size but on their knowledge of the words presented and the relationships established between pairs of familiar words.

Taken together, Experiments 1 and 2 demonstrate that 21-month olds are sensitive to the semantic–associative relationship between some pairs of words in their mental lexicon. In the context of the IPL task, this manifests itself through sustained attention to a target referent when the preceding word is related, but disrupted attention to the target when the preceding

word is unrelated. The results from Experiment 2 also suggest that these links may start to emerge around the age of 18 months, insofar as they demonstrated a clear repetition priming effect. We interpret these results as evidence for the emergence of a semantic system organized according to meaning relations.

We have been able to identify priming effects within two phonological manipulations: 21-month olds showed priming to semantic–associative related prime–target word pairs when they had different (Experiment 1) or same onsets (Experiment 2). Moreover, priming effects were observed when the target and the distracter words had the same (Experiment 1) or different (Experiment 2) onsets. Thus, it seems that at 21 months of age the effect of the related prime is strong enough to produce a priming effect when phonological competition exists between a target and a distracter word as well as in the potentially easier cases in which the target and the distracter have different onsets. In 18-month olds, a priming effect was obtained only in Experiment 2 where the repeated prime–target words had the same onsets and when the target–distracter names had different onsets. Further research is needed to clarify the importance of phonological overlap between prime–target words to facilitate priming effects.

Previous research has found priming effects for thematic, taxonomic and perceptual relationships during childhood (McCauley *et al.* 1976; Krackow & Gordon 1998; Nation & Snowling 1999). It is difficult to delimit the contribution of categorical, perceptual or conceptual relations on priming effects. In the present research, perceptual similarity between prime and target was not manipulated, thus it is not possible to identify the extent to which this factor contributed to the priming effect observed. However, if semantic–associative relations were merely based on categorical relations, irrespective of language, infants should have shown similar target preferences in both the Prime–Target and the Prime–Look conditions of Experiment 1. This did not occur. Although it is probable that the semantic effect encountered at 21 months of age is influenced by perceptual cues, categorical membership and conceptual knowledge, the results show a clear effect of semantic–associative relatedness between word pairs. The identification of semantic–associative links that influence infants’ online language processing provides support for a model of lexical acquisition in which words are integrated by interconnected nodes at the level of meaning.

Our results indicate that before infants are able to produce a large number of words, their lexicons show the beginnings of organization based on semantic principles that reflect the proximity of word meanings. We have not attempted in these experiments to discriminate between words that are semantically linked or associatively linked. In fact, the choice of stimuli, based on adult associative norms, would suggest that the priming effects reported in these experiments are driven by both semantic and associative factors. In more recent work (Arias-Trejo & Plunkett submitted), we have attempted to identify whether taxonomic relations (e.g. lorry–bike) or thematic relations (e.g. park–swing) alone lead to priming

effects using an experimental procedure similar to that described in the current work. We found no effect of taxonomic or thematic priming at 21 months of age. However, both taxonomic and thematic relations between words produced a priming effect at 24 months of age. It would appear that the strength of each type of relationship is not sufficiently consolidated to drive a priming effect until the infant is somewhat older. Nevertheless, the current demonstration of a priming boost for words that are both taxonomically and thematically related in 21-month olds indicates that the foundations of each type of relationship are already in place at this age.

What is the mechanism underlying the priming effect observed in these infants? Adult models of lexical semantic priming distinguish between distributed models of semantic memory (McRae & Boisvert 1998; Cree & McRae 2003) where lexical concepts are interconnected owing to their overlap in features and localist models (Collins & Loftus 1975) in which words are organized in a semantic network of interconnected nodes. Unfortunately, our current results do not adjudicate between these approaches. However, we have shown that sometime during the second half of the second year of life, infants establish a system of interconnected lexical meanings based on taxonomic and thematic (and perhaps other) relations. Furthermore, we have demonstrated that in younger infants and under certain task conditions there is little evidence for any interconnected system of meanings constraining lexical processing, such that unrelated words do not interfere with each other and related words do not facilitate processing. These early properties indicate that lexical concepts are 'islands' in semantic space. The task before us is to determine empirically how these islands coalesce into a system of meanings. We suggest that the properties of this coalescence have the potential to reveal the nature of the mental representations underlying the young and the mature lexical semantic system. Knowing how something is built can provide important clues as to how it operates. For example, if overlap in features provides a suitable metric for predicting how lexical concepts are added to an immature system of meanings then distributed approaches might be favoured. Assimilation of lexical concepts to the mental lexicon in a piecemeal fashion might favour a more localist approach. Given that we have now identified a clear-cut priming effect with infants, we are in a better position to identify the developmental trajectories characterizing the growth and structure of the mental lexicon.

ENDNOTE

¹Degrees of freedom are 55 instead of 57 because the three trials selected for two participants were missing trials or trials with unknown words as reported by parents.

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